MELT AND FLUID INCLUSIONS IN EVOLVED AND SIMPLE GRANITE PEGMATITES

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Selected examples from different types of pegmatites from different geologic environment – upper crust vs. lower crust – demonstrate, that the fluid and melt inclusions provide valuable data on the temperature, pressure and composition of the pegmatite-forming fluids, which are not available from any other source.

The Ehrenfriedersdorf granite-pegmatite complex, Erzgebirge, Germany

From melt and fluid inclusion studies, Thomas et al. (2000 and 2003) have shown, that in the case of the Variscan Ehrenfriedersdorf granite-pegmatite complex (Erzgebirge, Germany), complete miscibility between melt and fluid is possible even at considerably low pressure as suggested by Sowerby and Keppler (2002). The cause for this behaviour is due to the complex interplay of the volatiles H_2O, F, and Cl, the semivolatiles B_2O_3 and P_2O_5, and fluxing components such as Li_2O, Rb_2O, and Cs_2O along with the SiO_2 and Al_2O_3 in the melt. The most intriguing peculiarity of this system is the existence of a solvus with two coexisting pegmatite-forming melts at pressures $\leq$ 100 MPa (Thomas et al., 2000). Complete miscibility was attained at 712°C and 21.5 wt% H_2O. Further studies show, that this model represents an over simplification, because in the reality three or more phases coexist at or near the critical point: two melts, a hypersaline brine and a low-density fluid formed by periodic pressure fluctuations and boiling.

The Pechtelsgrün pegmatite

Melt and fluid inclusions in pegmatite quartz from the Pechtelsgrün/Vogtland tungsten deposit, Germany contain three different inclusion types within single growth zones: (i) crystallized melt inclusion composed mainly from muscovite and a fluid phase (solution + vapour bubble), (ii) fluid inclusion with a sassolite daughter crystal, and (iii) fluid inclusions with a large nahcolite daughter crystal. In some inclusions more than two nahcolite crystals are present.

Boric acid-rich fluid inclusions contain about 5.4 wt% NaCl and 9.0 wt% H_3BO_3. In addition to NaCl and H_3BO_3 this solution contains relatively high concentration of dissolved CO_2 as indicated by a strong Raman band at 1380 cm^{-1}. The hydrogencarbonate concentration is below the detection limit.

In related pegmatites with light blue topaz crystals the primary fluid inclusions are extremely rich in boron species, indicated by large daughter crystals of sassolite (H_3BO_3) and alkali tetrafluoroborates ($NaBF_4$, KBF_4, $RbBF_4$, $CsBF_4$) beside some unidentified phases.

The nahcolite-rich fluid inclusions contain 20.9 wt% $NaHCO_3$, 10.3 wt% NaCl, and 68.8 wt% H_2O. Such elevated nahcolite concentration is unusual for granite-related systems.

At room temperature the vapour bubble occupies about 28 vol% of the inclusion. During heating the bubble shrinks up to about 400°C and then enlarges quickly to a volume of about 50 vol%. At 403°C a new vapour bubble appears inside the large vapour bubble, showing the presence of three different phases: two liquid phases (the primary vapour phase changes into a liquid phase) and one vapour phase. At this temperature the original vapour phase converts temporarily into a liquid phase. The homogenisation which is reproducible occurs in the vapour phase by increasing the new formed vapour bubble at 500 $\pm$ 10°C. The following sequence of phase transitions can be observed (see Diamond, 1996):

solid + liquid + vapour $\Rightarrow$ liquid + vapour $\Rightarrow$ liquid 1 + liquid 2 + vapour $\Rightarrow$ liquid 1 + vapour $\Rightarrow$ vapour

The peralkaline pegmatite from the Ames Complex, Namibia

The Amis complex is a small, distinct intrusion of a peralkaline arfvedsonite granite at the SW edge of the Brandberg metaluminous granite in Namibia (Schmidt et al., 2002).

Numerous melt inclusions, ranging in size between 10 and 150 μm occur in pegmatite quartz. The chemical compositions of remelted inclusions is characterized by very high fluorine (~5wt%) and carbonate (~5.9wt%) concentrations and by a strong peralkaline character (A/CNK = 0.62). The element chemistry of the pegmatitic liquid is unique by some incompatible elements (Ti, Zr, and in part Ce, and Y) which are extremely enriched. For example, 10 000 ppm Zr in the pegmatite melt is in strong contrast to the values of 440 ppm Zr in the host granite. The solubility of the high field-strength element zirconium is directly related to the peralkalinity (mol. prop. of $Na_2O + K_2O)/Al_2O_3 > 1$).

Precambrian pegmatite from the Rønne granite, Bornholm Island, Denmark

In graphic quartz of the pegmatite there are isolated clusters with two types of inclusions. The one type is the CO_2-rich, however water-poor vapour inclusion, often containing a small nahcolite crystal of about 2-5 vol%. The other type is an extreme $NaHCO_3$-rich inclusion. In some cases these inclusions contain up to 80-90 vol% carbonates/hydrogencarbonates as well as a carbonate/hydrogencarbonate saturated solution and only a very small vapour bubble. According to Raman spectroscopic results the solid phases consist mainly from nahcolite (~70 vol%), aragonite (10 vol%), and small amounts of sodium and potassium carbonate and calcite. A small Raman band at 990 cm^{-1} indicates the presence of trace sulphates. In addition to inclusions with the high carbonate concentrations there are fluid inclusions with variable concentrations of carbonates (5-20 vol%). This inclusion type was probably formed by reaction with a secondary low temperature fluid. The mostly isometric nahcolite-rich, probably primary inclusions are trapped as carbonate melt globules.

This pegmatite is an example for simple pegmatites, often related to Precambrian granites, which crystallized at great depths (7-11 km) where the typical pegmatite-forming elements (B, F) are present only in traces.

Conclusions

According to our studies on natural fluid and melt inclusions, and also to our experimental work (Veksler et al., 2002, Veksler and Thomas, 2002) liquid immiscibility and the supercritical stage are key events in the evolution of pegmatites. Liquid immiscibility is not a singular event. These processes takes place at all times as long as there are melts, for example, also at the end of the melt-dominated stage in small subsystem compartments separated by large crystals of quartz, feldspar and others. In the following hydrothermal stage the primary melt signatures are often blurred or wiped out completely. The resulting lack of melt inclusions often led to misinterpretations of pegmatite genesis. In large pegmatite bodies (Tanco, Mozambique, Volhynia) the relationship between different inclusion types often is not recognizable. So, the often contradictory interpretation of the Volhynia pegmatite genesis can be explained simple by the apparent incoherence of different inclusion types. This connection is very seldom observable. In the relatively small pegmatite bodies of Ehrenfriedersdorf, Pechtelsgrün, and Königshain this relationship has been preserved. From our observation on natural melt and fluid inclusions and our new experimental work the Jahns-Burnham model (1969) completed by the liquid-liquid immiscible concept can explain more or less all steps of the genesis of granite pegmatites.

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